CHAPTER 2

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN FOR THE REMOVAL OF RADIUM AND URANIUM BY CATION AND ANION EXCHANGE TECHNOLOGIES

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLES

LIST OF ABBREVIATIONS

PSTP	Product-Specific Test Plan
FTO	Field Testing Organization
gpm/sf	Gallons per minute per square foot
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
meq/mL	milli-equivalent per milliliter
mg/L	milligrams per liter
mrem/yr	milli-radiation equivalent man per year
NPDES	National Pollutant Discharge Elimination System
NSF	NSF International
O&M	operation and maintenance
pCi/L	picocuries per liter
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
rpm	revolutions per minute
RSD	relative standard deviation
SCADA	Supervisory Control and Data Acquisition
SDWA	Safe Drinking Water Act
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WSWRD	Water Supply and Water Resources Division
WTP	water treatment plant

1.0 APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN

This document is the Environmental Technology Verification (ETV) Testing Plan for evaluation of for cation and anion exchange technologies to be used within the structure provided by the "EPA/NSF ETV Protocol For Equipment Verification Testing For The Removal Of Radioactive Chemical Contaminants: Requirements For All Studies". This Plan is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing of ion-exchange process equipment to achieve removal of dissolved radionuclides, such as radium and uranium.

In order to participate in the equipment verification process for ion-exchange processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of a PSTP. The FTO shall clearly specify in its PSTP the radionuclides targeted for removal and sampling program that shall be followed during Verification Testing. The PSTP should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the PSTP should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing program is to achieve removal of dissolved radionuclides, such as radium and uranium, present in feedwater supplies. The Manufacturer should establish a Statement of Performance Objectives (Section 3.0 General Approach) that is based upon removal of target radionuclides from feedwaters. The experimental design of the PSTP shall be developed to address the specific Statement of Performance Objectives established by the Manufacturer. Each PSTP shall include all of the included tasks, Tasks 1 to 8.

2.0 INTRODUCTION

Ion-exchange processes are currently in use for a number of water treatment applications ranging from removal of color, hardness, radium, uranium, and other constituents.

In order to establish appropriate operations, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Prefiltration processes ahead of ion-exchange systems are generally required to remove particulate material and to ensure provision of high quality water to the ion-exchange systems. For surface water applications, appropriate pretreatment, primarily for removal of particulate and microbiological species, must be applied as specified by the Manufacturer. In the design of the PSTP, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the ion-exchange process. The stipulated feedwater pretreatment process(es) shall be employed for upstream of the ion-exchange process at all times during the Equipment Verification Testing Program.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a State or accredited by a third-party organization (i.e., NSF) or the U.S. Environmental Protection Agency (USEPA) for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Objectives the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The Statement of Performance Objectives must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. Two examples of Statements of Performance Objectives that may be verified in this testing are:

1. This system is capable of achieving 90 percent removal of radium during a 60-day operation period at a loading rate of 1 gpm/cf of resin (temperature between 20 and 25°C) in feedwaters with radium concentrations less than 25 pCi/L and total hardness concentrations less than 200 mg/L as $CaCO_3$.

2. This system is capable of producing a product water with a radium concentration less than 5 pCi/L during a 60-day operation period at a loading rate of 1 gpm/cf of resin (temperature between 20 and 25°C) in feedwaters with radium concentrations less than 25 pCi/L and total hardness concentrations less than 200 mg/L as $CaCO_3$.

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Objectives. For each Statement of Performance Objectives proposed by the FTO and the Manufacturer in the PSTP, the following information shall be provided:

- percent removal of the targeted radionuclide;
- rate of treated water production;
- recovery;
- feedwater quality regarding pertinent water quality parameters;

- temperature;
- concentration of target radionuclide; and
- other pertinent water quality and operational conditions.

This ETV Testing Plan is broken down into 8 tasks, as shown in the Section 6.0, Overview of Tasks. These Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified by ETV. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the PSTP. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan.

4.0 BACKGROUND

This section provides an overview of the literature review related to dissolved radionuclide regulations, health effects, and contaminant removal by ion-exchange technologies, and ion-exchange technology design. These items will assist in the following:

- Defining various ion-exchange technologies capable of removing radionuclides;
- Defining ion-exchange technologies; and
- Describing the mechanisms that will help in qualifying and quantifying the removal efficiency of the ion-exchange technology tested.

4.1 Removal Processes

Water supply systems that use sources that contain high radionuclide concentrations will need to implement treatment techniques. Treatment processes that are available for the removal of radium and uranium include, but are not limited to, cation and anion exchange resins, zeolites, adsorptive media, reverse osmosis membranes, and lime softening.

This Plan discusses the use of ion-exchange technologies for the removal of dissolved radionuclides. Ion-exchange is a water treatment technique utilized for the removal of ionic contaminants from water. Therefore, the following section discusses the removal of Radium (Ra)-226, Ra-228, and uranium (U) using ion-exchange processes.

4.2 Radionuclide Removal by Ion-Exchange Technologies

Ion-exchange treatment methods involve the exchange of ions from the raw water with presaturant ions from an exchange material. There are cation and anion exchange technologies. They include the removal of positively charged ions by cation exchange and the removal of negatively charged ions by anion exchange. Both cation and anion exchange treat raw water with radionuclides by exchanging the radium cations or uranium anions with presaturant cations and anions in an exchange media, respectively. Cation exchange is also capable of removing major hardness causing cations (*e.g.*, calcium, magnesium, etc.). The merit of ion-exchange process is its reversible reaction. When ion-exchange capacity is depleted, using an excess of the presaturant ion regenerates the exhausted ion-exchange material.

4.2.1 Cation Exchange

Cation exchange systems are capable of removing radium from raw water supply sources. This is due to the fact that radium occurs in natural water as a cation. This process provides softening, as well as, removal of Ra-226 and Ra-228. Radium is a divalent cation similar to calcium or magnesium. The cation exchange occurs using a cation exchange resin with presaturant cations such as sodium or hydrogen. Water treatment by cation exchange occurs with a cycle of service, backwash, regeneration, and rinse. Raw water is passed through the ion-exchange bed, and hardness causing ions, including radium, are replaced with sodium or hydrogen ions from the resin.

Almost complete hardness and radium removal can be achieved. Pretreatment for iron, if present, may increase the effectiveness of the cation exchange process, as well as, minimize regeneration and backwashing.

When the resin becomes exhausted or the finished water quality is less than desired, the ion-exchange bed is regenerated. Before a regeneration cycle, the exhausted resin bed should be backwashed. The backwash cycle is an up-flow wash performed at a manufacturer specified rate to provide removal of the entrapped particles. The backwash should be able to accomplish to cause 40 to 75 percent expansion of the resin bed.

The regenerant is typically a concentrated salt solution or brine (*e.g.,* 6-10 percent NaCl solution). The volume of the regenerant solution is only a fraction of the total volume of the raw water processed, resulting in a concentrated waste stream. The manufacturer will specify the pounds of salt per cubic foot of resin. When the regeneration cycle has been completed, a rinse cycle is provided to remove excess brine before a service cycle starts.

Disposal of the waste regenerant brine and backwash water is necessary. Disposal of the waste brine is limited by the radium concentration. The permitting of a disposal process for the ion-exchange treatment units may be a difficult process.

4.2.2 Anion Exchange

Anion exchange system operations are very similar to cation exchange systems. Anion exchange systems are capable of removing uranium from raw water supply sources. This is due to the fact that most uranium occurs in natural water as an anion. The design of anion exchange process is greatly different from the cation exchange process because the removal capacity for uranium is far greater than radium or hardness although it uses the same type equipment, and the same process flow scenario. Specific gravities of anion exchange resins are lower than that of cation exchange resins. Therefore, the backwashing practice for anion exchange process needs to adopt a lower rate than cation exchange process.

Anion exchange does not provide hardness removal such as cation exchange. It does remove alkalinity (HCO_3^-) (low initial pH), sulfate, nitrate and arsenic during the first part of the cycle when operated to remove uranium. Since uranium is the most preferred of all anions, as time goes on uranium will "push" these other anions from the bed causing spikes and potential problems with sulfate, nitrate and arsenic. The pH will be depressed as a result. This should be considered in the testing of any anion exchange process.

4.3 Ion-Exchange Technology Design Considerations

The design capacity of an ion-exchange unit and associated resin can be determined based on the total amount of presaturant ions (counter ions) capable of exchange. The effective capacity is the percentage of the total capacity that may be utilized based on empty bed contact time, regeneration level, and regenerant flow rate. The capacity of an ion-exchange bed prior to exhaustion can be defined as the maximum number of equivalent ions that can be removed from solution per volume of resin.

Ion-exchange design considerations include, but are not limited to:

- Well pump capacity (gpm)
- Volumetric flow rate (gpm/cf or bed volumes per hour (BV/hr))
- Surface loading rates (gpm/sf)
- Hardness
- Prefilters
- Ion-Exchange Vessels
- Resin type
- Regenerant wastewater tank capacity
- Water temperature
- Empty bed contact time
- Water quality

Ion-exchange treatment units generally consist of vessels which contain the ion-exchange resin, a storage tank for regenerant salt, and a vessel for mixing of the brine solutions or brine eductor, and associated valves, pumps, piping, and controls. The ion-exchange tank or vessel may be pressurized or an open system type. For certain water sources, pretreatment may be required. However, pretreatment is not normal for water supplies containing uranium and/or radium. The diameter of the ion-exchange pressure vessel is typically limited to 12 feet in diameter.

The size of commercially available cation and anion exchange resins are generally in the range of 16 to 50 screen mesh size (US standard sieve). A variety of resins are available from various manufacturers. Flow rates are defined as volumetric flow rate (bed volume per hour (BV/hr)) and surface area loading rate (gpm/sf). The volumetric flow rate is inversely related to the contact time of the solution and the resin. The surface loading rate is a measure of the raw water flow rate through the resin bed. Blending is rarely used or permitted by regulatory agencies at the State level. When blending is utilized, only a fraction of the raw water is treated with the ion-exchange material. It is important that the ion-exchange bed and the blending ratios are designed to provide adequate removal of radionuclides to meet regulatory limits.

4.4 Waste Disposal

Waste disposal options include hauling and discharge into a wastewater treatment facility, injection into a disposal well or transportation to a concentrate disposal facility. State and local regulatory agencies should be contacted to establish guidelines for treatment and disposal of wastes generated by ion-exchange processes. The regenerant waste stream from the ion-exchange regeneration process must be treated and/or disposed of in some manner. Effective regenerant disposal methods depend on the spent regenerant water quality, local regulations and site specific factors (AWWARF 1993). The handling and disposal of the wastes generated by treatment technologies removing naturally occurring radionuclides from drinking water pose concerns to the water supplier, to local and State governments and to the public at large. The potential handling hazards associated with radionuclides warrant the development of a viable ion-exchange regenerate disposal method. Information regarding concentrate disposal options can be found in *Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally Occurring Radionuclides* (USEPA, 1990). The document first addresses the management of radionuclide wastes by first describing the potential sources of these wastes (i.e., water treatment processes). Then there is a brief review of the known information on the radionuclide composition of the associated treatment wastes. The document then describes the plausible disposal alternatives and provides background information from related programs that should assist facilities in selecting a responsible option. The following are disposal options that must be approved by the State or local government prior to implementation of a waste disposal program.

<u>Liquid Waste Disposal</u>

- Direct discharge into storm sewers or surface water.
- Discharge into sanitary sewer.
- Deep well injection.
- Drying or chemical precipitation.

<u>Solid Waste Disposal</u>

- Temporary lagooning (surface impoundment).
- Disposal in landfill.
  a) Disposal without prior treatment.
  b) With prior temporary lagooning.
  c) With prior mechanical dewatering.
- Application to land (soil spreading/conditioning).

- Disposal at State licensed low-level radioactive waste facility.

5.0 DEFINITION OF OPERATIONAL PARAMETERS

The following terms are presented here for subsequent reference in this test plan:

- **Anion/Cation Exchange –** Water treatment process where water is passed through a filter bed of exchange material. Anions/cations in the insoluble exchange material are displaced by ions from the raw water feed. The exchange material is used until the material is exhausted. The exchange material resin is regenerated with a solution such as sodium chloride.

- **Package Plant** - A complete water treatment system including all components from the connection to the raw water(s) intake through discharge to the distribution system.

- **Product-Specific Test Plan (PSTP)** - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF ETV Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.

- **Raw** - Input stream to the ion-exchange process prior to any pretreatment.

- **Verification Statement** - A written document that summarizes a final report reviewed and approved by NSF on behalf of the USEPA or directly by the USEPA.

- **Water System** - The water system that operates using water treatment equipment to provide potable water to its customers.

6.0 OVERVIEW OF TASKS

This Plan is applicable to the testing of water treatment equipment utilizing ion-exchange technologies that include cation and anion exchange. Testing of ion-exchange equipment will be conducted by a NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analyses will be performed by a state-certified or third party- or EPA- accredited laboratory. This Plan provides objectives, work plans, schedules, and evaluation criteria for the required tasks associated with the equipment testing procedure.

The following is a brief overview of the tasks that shall be included as components of the Verification Testing Program and PSTP for removal of dissolved radionuclides.

- **Task 1: Equipment Verification Testing Plan –** Operate ion-exchange and associated water treatment equipment for a 60-day testing period to collect data on water quality and equipment performance.

- **Task 2: Characterization of Raw Water –** Obtain chemical, biological and physical characterization of the raw water. Provide a brief description of the watershed that provides the raw water to the water treatment plant.
- **Task 3: Operations and Maintenance (O&M)** - Evaluate an O&M manual for each system submitted. The O&M manual shall characterize ion-exchange process design, outline an ion-exchange regeneration procedure or procedures, and provide an ion-exchange regenerant disposal plan.
- **Task 4: Data Collection and Management –** Establish an effective field protocol for data management between the Field Testing Organization and NSF.
- **Task 5: Radionuclide Removal -** Evaluate ion-exchange technology operations in relation to verified raw water quality.
- **Task 6: Finished Water Quality –** Evaluate the water quality produced by the ion-exchange technology as it relates to raw water quality and operational conditions.
- **Task 7: Quality Assurance / Quality Control (QA/QC) –** Develop a QA/QC protocol for Verification Testing. This is an important item that will assist in obtaining an accurate measurement of operational and water quality parameters during ion-exchange equipment Verification Testing.
- **Task 8: Cost Evaluation** - Develop O&M costs for the submitted ion-exchange technology and equipment.

7.0 TESTING PERIODS

The required tasks of the ETV Equipment Verification Testing Plan (Tasks 1 through 8) are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. The schedule for equipment monitoring during the 60-day testing period shall be stipulated by the FTO in the PSTP, and shall meet or exceed the minimum monitoring requirements of this testing plan. The FTO shall ensure in the PSTP that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the "EPA/NSF ETV Protocol For Equipment Verification Testing For The Removal Of Radioactive Chemical Contaminants: Requirements For All Studies". The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein.

For ion-exchange process treatment equipment, factors that can influence treatment performance include:

- Feedwaters with high seasonal concentrations of inorganic constituents and total dissolved solids (TDS). These conditions may increase finished water concentrations of inorganic chemical contaminants;
- Cold water, encountered in winter or at high altitude locations;

- High concentrations of natural organic matter (measured as total organic carbon (TOC)), which may be higher in some waters during different seasonal periods;
- High turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single 60-day period during the Verification Testing program. Ion-exchange testing conducted beyond the required 60-day testing may be used for fine-tuning of ion-exchange performance or for evaluation of additional operational conditions. During the testing periods, evaluation of regeneration efficiency and finished water quality can be performed concurrent with ion-exchange operation testing procedures.

8.0 TASK 1: EQUIPMENT VERIFICATION TEST PLAN

8.1 Introduction

The equipment verification for ion-exchange technologies for radionuclide removal shall be conducted by a NSF-qualified, Field Testing Organization (FTO) that is selected by the Manufacturer. Water quality analytical work to be completed as a part of this ETV Plan shall be contracted with a state-certified or third party- or EPA- accredited laboratory. For information on a listing of NSF-qualified FTOs and state-certified or third party- or EPA- accredited laboratories, contact NSF.

8.2 Objectives

The objective of this task is to operate the equipment provided by a Manufacturer, for the conditions and time periods specified by NSF and the Manufacturer.

8.3 Work Plan

8.3.1 Equipment Verification Test Plan

Table 8.1 presents the Tasks that are included in this Plan and will be included in the PSTP for radionuclide removal by ion-exchange technologies. Any Manufacturer wanting to verify the performance of their equipment shall perform these Tasks. The Manufacturer shall provide full detail of the procedures to be followed for each item in the PSTP. The FTO shall specify the operational conditions to be verified during the Verification Testing.

In the design of the PSTP, the FTO shall stipulate which pretreatments are appropriate for application before the selected ion-exchange processes. The recommended pretreatment process(es) shall then be employed by the Manufacturer for raw water pretreatment during implementation of the Equipment Verification Testing Program.

TABLE 8.1: Task Descriptions

No.	Task	Description
1	Test Plan	Water treatment equipment shall be operated for a minimum of one 60 day test period to collect data on water quality and equipment performance.
2	Characterization of Raw Water	Obtain chemical, microbiological and physical characterization of the raw water.
3	O&M	Evaluate O&M manual for process.
4	Data Management	Develop data protocol between FTO and NSF.
5	Contaminant Removal	Evaluate radionuclide removal at selected set of operational conditions.
6	Finished Water Quality	Evaluate water quality at selected set of operational conditions.
7	QA/QC	Enforce QA/QC standards.
8	Cost Evaluation	Provide O&M costs of system.

8.3.2 Routine Equipment Operation

During the time intervals between equipment verification runs, the water treatment equipment may be used for production of potable water. If the equipment is being used for the production of potable water, routine operation for water production is expected. The operating and water quality data collected and furnished to the local regulatory agency should also be supplied to the NSF-qualified FTO.

8.4 Analytical Schedule

The entire equipment verification shall be performed over a 60-day period (not including time for system shakedown and mobilization). At a minimum, one 60-day period of Verification Testing shall be conducted in order to provide equipment testing information for ion-exchange technology performance.

The required tasks for the equipment verification are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. Ion-exchange technology testing conducted beyond the required 60-day testing may be used for fine-tuning of ion-exchange performance or for evaluation of additional operational conditions. During the 60-day testing period, evaluation of finished water quality can be performed concurrent with the percent removal testing procedures.

8.5 Evaluation Criteria

The equipment testing period will include a Verification Test of at least 60-days.

9.0 TASK 2: CHARACTERIZATION OF RAW WATER

9.1 Introduction

A characterization of raw water quality is needed to determine if the concentrations of Ra-226, Ra-228, and uranium, or other raw water contaminants are appropriate for the use of ion-exchange processes. The feedwater quality can influence the performance of the equipment.

9.2 Objectives

One reason for performing a raw water characterization is to obtain at least one-year of historical raw water quality data from the raw water source. The objective is to:

- demonstrate seasonal effects on the concentration of radionuclides; and
- develop maximum and minimum concentrations for the contaminant.

If historical raw water quality is not available, a raw water quality analysis of the proposed feedwater shall be performed prior to equipment Verification Testing.

9.3 Work Plan

The characterization of raw water quality is best accomplished through the performance of laboratory testing and the review of historical records. Sources for historical records may include municipalities, laboratories, USGS (United States Geological Survey), USEPA, and local regulatory agencies. If historical records are not available preliminary raw water quality testing shall be performed prior to equipment Verification Testing. The specific parameters of characterization will depend on ion-exchange process that is being tested. The following characteristics should be reviewed and documented:

- Radium-226
- Radium-228
- Uranium
- Temperature
- pH
- TDS
- Total Hardness
- Calcium Hardness
- Total Alkalinity
- Turbidity
- Total Organic Carbon
- True Color
- Chloride
- Sulfate
- Hydrogen Sulfide
- Fluoride
- Iron
- Manganese
- Nitrate
- Sodium
- Phosphate
- Arsenic

Data collected should reflect seasonal variations in the above data if applicable. This will determine variations in water quality parameters that will occur during Verification Testing. The data that is collected will be shared with NSF so that the FTO can determine the significance of the data for use in developing a test plan. If the raw water source is not characterized, the testing program may fail, or results of a testing program may not be considered acceptable. A description of the raw water source should also be included with the feedwater characterization. The description may include items such as:

- size of watershed;
- topography;
- land use;
- nature of the water source; and
- potential sources of pollution.

9.4 Schedule

The schedule for compilation of adequate water quality data will be determined by the availability and accessibility or historical data. The historical water quality data can be used to determine the suitability of ion-exchange processes for the treatment for the raw source water. If raw water quality data is not available, a preliminary raw water quality testing should be performed prior to the Verification Testing of the ion-exchange equipment.

9.5 Evaluation Criteria

The feedwater quality shall be evaluated in the context of the Manufacturer's Statement of Performance Objectives for the removal of radionuclides. The feedwater should challenge the capabilities of the chosen equipment, but should not be beyond the range of water quality suitable for treatment by the chosen equipment. For ion-exchange processes, a complete scan of water quality parameters may be required in order to determine pretreatment criteria.

10.0 TASK 3: OPERATIONS AND MAINTENANCE MANUAL

An operations and maintenance (O&M) manual for ion-exchange technologies to be tested for radionuclide removal shall be included in the Verification Testing evaluation.

10.1 Objectives

The objective of this task is to provide an O&M manual that will assist in operating, troubleshooting and maintaining ion-exchange process performance. The O&M manual shall:

- characterize ion-exchange process design;
- outline an ion-exchange resin regeneration procedure or procedures; and
- provide a waste disposal plan.

The waste disposal plan must be approved by the appropriate regulatory authority for the verification period before verification testing begins. A fully developed waste disposal plan is required because of the radionuclides that have been concentrated in the waste stream. Criteria for evaluation of the equipment's O&M Manual shall be compiled and then evaluated and commented upon during verification by the FTO. An example is provided in Table 10.1.

The purpose of O&M information is to allow utilities to effectively choose a technology that their operators are capable of operating, and provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

10.2 O&M Work Plan

Descriptions of ion-exchange technology unit process design shall be developed for the removal of radionuclides. Ion-exchange technologies shall include the design criteria and equipment characteristics. Examples of information required relative to the ion-exchange design criteria and characteristics are presented in Tables 10.2 and 10.3, respectively.

Depending on the raw water quality, periodic regeneration of the ion-exchange resin will be required. Regeneration of resin will be performed as necessary per manufacturer specifications. Resin may also require periodic replacement. Resin regeneration and material replacement should be noted so that it may be considered for the verification of the equipment.

TABLE 10.1: Operations & Maintenance Manual Criteria - Ion-Exchange Equipment

MAINTENANCE:
The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as: • flow meters • pressure gauges • pumps • motors • valves • chemical feeders • ion-exchange vessel The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as: • resin • piping
OPERATION:
The manufacturer should provide readily understood recommendation for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are: Chemical feeders (if applicable): • calibration check • settings and adjustments - how they should be made • dilution of chemicals - proper procedures Monitoring and observing operation: • removal calculations • pressure readings/monitoring

TABLE 10.1: Operations & Maintenance Manual Criteria - Ion-Exchange Equipment (continued)

OPERATION (continued):

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water flow to plant;
- when the water flow rate through the equipment can not be controlled;
- no chemical feed;
- automatic operation (if provided) not functioning;
- no electric power; and

The following are recommendations regarding operability aspects of ion-exchange technology processes. These aspects of equipment operation should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program. During Verification Testing, attention shall be given to equipment operability aspects.

- are chemical feed pumps calibrated?
- are flow meters present and have they been calibrated?
- are pressure gauges calibrated?
- are pH meters calibrated?
- can regeneration be done automatically?
- does remote notification occur (alarm) when pressure increases > 15% or flow drops > 15%?

The reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Operating Conditions and Treatment Equipment Performance, in the Cation and Anion Exchange Test Plan.

TABLE 10.2: Ion-Exchange Technology Design Criteria Reporting Items

Parameter	Unit
Type of unit	
Number of units	
Average flow rate (gpm)	
Maximum flow rate to unit (gpm)	
Minimum flow rate to unit (gpm)	
Resin type	
Resin volume (cf)	
Surface area at the resin/water interface (sf)	
Water temperature (^oC)	
Raw water Ra-226 concentration (pCi/L)	
Raw water Ra-228 concentration (pCi/L)	
Raw water Uranium concentration (pCi/L)	
Percent removal of Ra-226 (%)	
Percent removal of Ra-228 (%)	
Percent removal of Uranium (%)	
Pressure loss through system (psi)	
Service run time (hr)	
Empty bed contact time (min)	

TABLE 10.3: Ion-Exchange Equipment Characteristics

Parameter	Unit
Technology Manufacturer	
Equipment model number	
Resin type	
Filter area (sf)	
Design hydraulic loading rate (gpm/sf)	
Design pressure (psi)	
Standard testing removal (%)	
Standard testing pH	
Standard testing temperature (°C)	
Design concurrent flow velocity (fps)	
Maximum flow rate to the unit (gpm)	
Minimum flow rate to the unit (gpm)	
Acceptable range of operating pressures	
Acceptable range of operating pH values	
Typical pressure drop across a single unit (ft)	
Pumping requirements	
Suggested regeneration procedures	
Suggested resin replacement schedule	
Type of construction	
Estimated Purchase Price	
Other	

Note: Some of this information may not be available, but this table should be filled out as completely as possible for each technology tested

11.0 TASK 4: DATA COLLECTION AND MANAGEMENT

11.1 Introduction

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets, and manual recording of operational parameters for the ion-exchange equipment on a daily basis.

11.2 Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for verification purposes. Chain-of-Custody protocols will be developed and adhered to.

11.3 Work Plan

11.3.1 Operation Data Collection and Documentation

The following protocol has been developed for data handling and data verification by the FTO. In addition to daily operational data sheets, a Supervisory Control and Data Acquisition (SCADA) system could be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into electronic spreadsheets. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of ion-exchange equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

Field testing operators shall record data and calculations by hand in laboratory notebooks for a minimum of three times per day. (Daily measurements shall be recorded on data log sheets as appropriate. Figure 12.2 presents an example of a daily log sheet.) The laboratory notebook shall provide copies of each page. The original notebooks shall be stored on-site; the copied sheets shall be forwarded to the project engineer of FTO at least once per week during the 60-day testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include:

- descriptions of the equipment and test runs;
- names of visitors; and
- descriptions of any problems or issues.

Such descriptions shall be provided in addition to experimental calculations and other items.

11.3.2 Data Management

The database for the project shall be set up in the form of custom designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the field laboratory analysis notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time.

Following data entry, the spreadsheet shall be printed and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hardcopies and corrected on the screen, and then the corrected recorded calculations will also be checked and confirmed. The field testing operator or engineer performing the entry or verification step shall initial each step of the verification process.

Each experiment (e.g. each ion-exchange technology test run) shall be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA- accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the FTO. This data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.3.3 Statistical Analysis

For the analytical data obtained during Verification Testing, 95% confidence intervals shall be calculated by the FTO for selected water quality parameters. The specific Plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. When presenting the data, maximum, minimum, average and standard deviation should be included.

Calculation of confidence intervals shall not be required for equipment performance obtained during the equipment Verification Testing Program. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period.

12.0 TASK 5: RADIONUCLIDE REMOVAL

12.1 Introduction

The removal of Ra-226, Ra-228, and uranium from drinking water supplies is accomplished by ion-exchange treatment. The effectiveness of ion-exchange processes for radionuclide removal will be evaluated in this task. Assessment of treatment technologies will be assessed based on percent removal of Ra-226, Ra-228, and uranium.

12.2 Experimental Objectives

The objectives of this task are to demonstrate:

- Operational conditions for the ion-exchange equipment;
- Radionuclide removal achieved by the ion-exchange equipment; and
- Necessary regeneration and replacement of resin.

Initial raw water quality shall be measured prior to system start-up and then monitored accordingly over the 60-day testing period using the sample frequency provided in Table 12.2. It should be noted that the objective of this task is not process optimization, but rather verification of ion-exchange operation at the operating conditions specified by the Manufacturer, as it pertains to percent removal of radium and uranium.

12.3 Work Plan

Determination of ideal ion-exchange operating conditions for a particular water may require as long as one year of operation. The cycle period for uranium could easily be greater than a one-year period allocated and the virgin run is much better than subsequent runs. The superior performance in the virgin run is also true for radium removal by cation exchange. For this task, the Manufacturer shall specify the operating conditions to be evaluated in the 60-day (minimum) verification testing period (24-hour continuous operation) and shall supply written procedures on the operation and maintenance of the ion-exchange system. The Manufacturer shall specify the primary hydraulic loading rate at which the equipment is to be verified. Additional operating conditions can be verified in separate 60-day testing periods.

After set-up and "shakedown" of the ion-exchange equipment, ion-exchange operation should be established at the loading rate to be verified. Testing of additional operational conditions could be performed by extending the number of 60-day testing periods beyond the initial 60-day test period required by the Verification Testing Program at the discretion of the Manufacturer and their designated FTO.

Additional 60-day periods of testing may also be included in the Verification Testing Plan in order to demonstrate ion-exchange performance under different raw water quality conditions. At a minimum the performance of the ion-exchange equipment relative to radionuclide removal shall be documented during those periods of variable raw water conditions. The Manufacturer shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 60-day testing period, as required above for each additional set of operating conditions.

12.4 Ion-Exchange Removal Efficiencies

12.4.1 Operational Data Collection

Removal efficiencies of radionuclides from raw water will be assessed by the percentage of removal from the source water. Measurement of influent raw water flow and pressure and finished water flow and pressure shall be collected at a minimum of three times per day. Table 12.1 is an example of a daily operational data sheet for an ion-exchange system. This table is presented for informational purposes only. The actual forms will be submitted as part of the test plan and may be site-specific.

Water quality should be analyzed prior to start-up and then every two weeks for the parameters identified in Table 12.2, except for radionuclides, which will be monitored prior to start-up and then weekly. Power usage for operation of the ion-exchange equipment shall also be closely monitored and recorded by the FTO during the 60-day testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements:

- pumping requirements;
- size of pumps;
- name-plate;
- voltage;
- current draw;
- power factor;
- peak usage; etc.

In addition, measurement of power consumption, chemical consumption shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals.

12.4.2 Feedwater Quality Limitations

The characteristics of raw waters used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the removal data for each period. Accurate reporting of such raw water characteristics is critical for the Verification Testing Program, as these parameters can substantially influence the range of ion-exchange performance and treated water quality under variable raw water quality conditions.

- Evaluation criteria and minimum reporting requirements.
- Plot graph of raw and finished Ra-226, Ra-228, and uranium concentrations over time for each 60-day test period.
- Plot graph of removal of Ra-226, Ra-228, and uranium over time for each 60-day test period.

TABLE 12.1: Daily Operations Log Sheet for an Ion-Exchange System

Date:

Parameter	Measurement 1	Measurement 2	Measurement 3
Time			
Initial			
Raw Water			
Q_{raw} (gpm)			
Ra-226$_{raw}$ (before pretreatment) (pCi/L)			
Ra-226$_{raw}$ (after pretreatment) (pCi/L)			
Ra-228$_{raw}$ (before pretreatment) (pCi/L)			
Ra-228$_{raw}$ (after pretreatment) (pCi/L)			
Uranium$_{raw}$ (before pretreatment) (pCi/L)			
Uranium$_{raw}$ (after pretreatment) (pCi/L)			
P_{raw} (psi)			
pH_{raw} (before pretreatment)			
pH_{raw} (after pretreatment)			
T_{raw} (°C)			
Ion-exchange Vessel			
Q (gpm)			
Ra-226 (pCi/L)			
Ra-228 (pCi/L)			
Uranium (pCi/L)			
P (psi)			
Finished			
Q_{fin} (gpm)			
Ra-226$_{fin}$ (pCi/L)			
Ra-228$_{fin}$ (pCi/L)			
Uranium$_{fin}$ (pCi/L)			
P_{fin} (psi)			
Regeneration (@ what % brine or NaCl)			
Q_{regen} (gpm)			
P_{regen} (psi)			

TABLE 12.2: Operating and Water Quality Data Requirements for Ion-Exchange Processes Over the 60-day Testing Period

Parameter	Frequency for Sampling
Raw Water Flow	3 / Daily
Finished Water Flow	3 / Daily
Regenerant Flow	3 / Daily
Raw Water Pressure	3 / Daily
Finished Water Pressure	3 / Daily
Regenerant Pressure	3 / Daily
List Each Chemical Used, And Dosage	Daily Data Or Monthly Average
Hours Operated Per Day	Daily
Hours Operator Present Per Day	Monthly Average
Power Consumption (kWh/Million Gallons)	Monthly
Independent check on rates of flow	Weekly
Independent check on pressure gages	Weekly
Verification of chemical dosages	Monthly
Feed Water and Finished Water Characteristics	
Radium-226	Weekly
Radium-228	Weekly
Uranium	Weekly
Gross Alpha and Beta Emitters	Weekly
Temperature	3 / Daily
pH	3 / Daily
TDS/Conductivity	3 / Daily
Turbidity	Every two weeks
True Color	Every two weeks
Total Organic Carbon	Every two weeks
Total Alkalinity	Every two weeks
Total Hardness	Every two weeks
Calcium Hardness	Every two weeks
Sodium	Every two weeks
Chloride	Every two weeks
Iron	Every two weeks
Manganese	Every two weeks
Sulfate	Every two weeks
Fluoride	Every two weeks
Nitrate	Every two weeks
Hydrogen Sulfide	Every two weeks
Arsenic	Every two weeks

13.0 TASK 6: FINISHED WATER QUALITY

13.1 Introduction

Water quality data shall be collected for the finished water as provided previously in Table 12.2. At a minimum, the required sampling shall be one initial sampling at start-up followed by the sample frequency presented in Table 12.2. The finished water samples should be collected when the raw water samples are collected. Water quality goals and target removal goals for the ion-exchange equipment should be proven and reported in the PSTP.

13.2 Objectives

The objective of this task is to verify the Manufacturer's objectives. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing has been provided in this document. The actual water quality parameters selected for testing and monitoring shall be stipulated in the PSTP.

13.3 Work Plan

The PSTP shall identify the treated water quality objectives to be achieved in the Statement of Performance Objectives of the equipment to be evaluated in the Verification Testing Program. The PSTP shall also identify in the Statement of Performance Objectives the radionuclide removal that shall be monitored during equipment testing. The Statement of Performance Objectives prepared by the PSTP shall indicate the range of water quality under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the drinking water treatment systems participating in the Ion-Exchange Process Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this Ion-Exchange Process Plan is oriented towards removal of Ra-226, Ra-228, and uranium, the Manufacturer may want to look at the treatment systems removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. A state-certified or third party- or EPA- accredited laboratory shall perform analysis of the remaining water quality parameters. Representative methods to be used for measurement of water quality parameters in the field and lab are identified in Table 13.1. Where appropriate, the Standard Methods reference numbers and USEPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the state-certified or third party- or EPA- accredited laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain-of custody requirements, as specified by the analytical lab.

TABLE 13.1: Water Quality Analytical Methods

Parameter	AWWA Method [1]	EPA Method [2]
Radium-226	7500-Ra	903.1
Radium-228	7500-Ra	---
Uranium	7500-U	908.0
Gross Alpha and Beta Emitters	7110	900.0
Temperature	2550	170.1
pH	4500-H^+	150.2
TDS/Conductivity	2510	120.1
Turbidity	2130	180.1
True Color	2120	110.2
Total Organic Carbon	5310	415.2
UV Absorbance (254 nm)	5910	---
Total Alkalinity	2320	310.2
Total Hardness	2340	130.2
Calcium Hardness	3500-Ca	215.2
Sodium	3500-Na	273.1
Chloride	4500-Cl^-	325.1
Iron	3500-Fe	236.1
Manganese	3500-Mn	243.1
Sulfate	4500-SO_4^{-2}	375.4
Fluoride	4500-F^-	340.1
Nitrate	4500-NO_3^-	352.1
Hydrogen Sulfide	4500-S^{-2}	---
Arsenic	3114	206.3

1) AWWA, Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1999.

2) EPA, Methods and Guidance for Analysis of Water, EPA 821-C-97-001, April 1997.

13.4 Analytical Schedule

13.4.1 Removal of Radioactive Chemical Contaminants

During the steady-state operation of each ion-exchange testing period, radionuclide mass balances shall be performed on the raw, backwash, and finished water in order to determine the radionuclide removal capabilities of the ion-exchange system, as well as the potential of the radionuclide to accumulate on the resin. Use the following mass balance equation:

$$Q_{raw}\, C_{raw} = Q_{backwash}\, C_{backwash} + Q_{finished}\, C_{finished} + \text{Accumulation}$$

13.4.2 Raw Water Characterization

At the beginning of each ion-exchange testing period utilizing a single-set of operating conditions, the raw water and finished water shall be characterized by an initial set of water quality parameters as identified in Table 12.2.

13.4.3 Water Quality Sample Collection

Water quality data shall be collected at established intervals during each period of ion-exchange equipment testing as identified in Table 12.2. The minimum monitoring frequency for the required water quality parameters is once at start-up and weekly for radionuclides and every two weeks for the remaining water quality parameters. The water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling.

13.4.4 Raw Water Quality Limitations

The characteristics of feedwater encountered during each 60-day testing period shall be explicitly stated. Accurate reporting of such raw water characteristics such as those identified in Table 12.2 is critical for the Verification Testing Program, as these parameters can substantially influence ion-exchange performance.

13.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal or reduction of radionuclides.
- Water quality and removal goals specified by the Manufacturer.

14.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL

14.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the ion-exchange process equipment and the measured water quality parameters shall be maintained during the Equipment Verification Testing Program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 QA/QC Work Plan

Equipment flow rates and associated transmitter signals should be calibrated and verified on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate, and into a flow stream that is operating at the expected flow rate. This will provide correct chemical concentrations in the flow stream. In-line monitoring equipment such as flow meters, etc. shall be checked monthly to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

When collecting water quality data, all system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the finished water flow rate by the "bucket test" method. This would consist of filling a calibrated vessel to a known volume and measuring the time to fill the vessel with a stopwatch. This will allow for a direct check of the system flow measuring devices.

14.3.1 Daily QA/QC Verification

- On-line pH meters (check and verify components)
- On-line conductivity meter (check and verify components)

14.3.2 Monthly QA/QC Verification

- Chemical feed pump flow rates (verify volumetrically over a specific time period) if used (Note: ion-exchange process does not use chemicals other than salt in most cases, unless pH adjustment is deemed necessary or acid/base regenerants are used)
- On-line flow meters/rotometers (clean equipment to remove any debris or microbiological buildup and verify flow volumetrically to avoid erroneous readings)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter).
- Piping (verify good condition of all piping and connections, replace if necessary)

14.4 Analytical Methods

Use of either bench-top field analytical equipment will be acceptable for the Verification Testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. However, standard and uniform calibration and standardization techniques that are approved should be employed. Table 13.1 lists American Water Works Association (AWWA) and EPA standard methods of analysis.

15.0 TASK 8: COST EVALUATION

This Plan includes the assessment of costs of verification with the benefits of ion-exchange processes over a wide range of operating conditions. Therefore, this Plan requires that one set of operating conditions be tested over a 60-day testing period. The equipment Verification Tests will provide information relative to systems, which provide desired results and the cost, associated with the systems. Design parameters are summarized in Table 15.1. These parameters will be used with the equipment Verification Test costs to prepare cost estimates for operation of the equipment.

Table 15.1: Design Parameters for Cost Analysis

Design Parameter	Specific Utility Values
Total required plant production (mgd)	
By-pass flow rate (mgd)	
Resin Type	
Resin Volume (cf)	
Surface loading rate (gpd/sf)	
Empty bed contact time (min)	

Operation and maintenance (O & M) costs realized in the equipment Verification Test can be utilized for cost estimates. O & M costs for each system will be determined during the equipment Verification Tests. The O & M costs that will be recorded and compared during the Verification Test include:

- Labor;
- Electricity;
- Chemical Dosage; and
- Equipment Replacement Frequency.

The O & M costs will vary based on geographic location.

O & M costs should be provided for each ion-exchange process that is tested. In order to receive the full benefit of the equipment Verification Test Programs, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the Verification Tests. A summary of O & M costs are outlined in Table 15.2.

Table 15.2: Operations and Maintenance Cost

Cost Parameter	Specific Values
Labor rate + fringe ($/personnel-hour)	
Labor overhead factor (% of labor)	
Number of O&M personnel hours per week	
Power consumption (kWh/Million Gallons)	
Electric rate ($/kWh)	
Cost of resin ($)	
Resin replacement (# times/year)	
Cost of chemicals ($)	
Chemical dosage (per week)	
Disposal costs ($)	

16.0 SUGGESTED READINGS

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